Update on $K_{L,S}\rightarrow\pi^+\pi^-\gamma$

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KTeV meeting
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Outline For Today's Talk

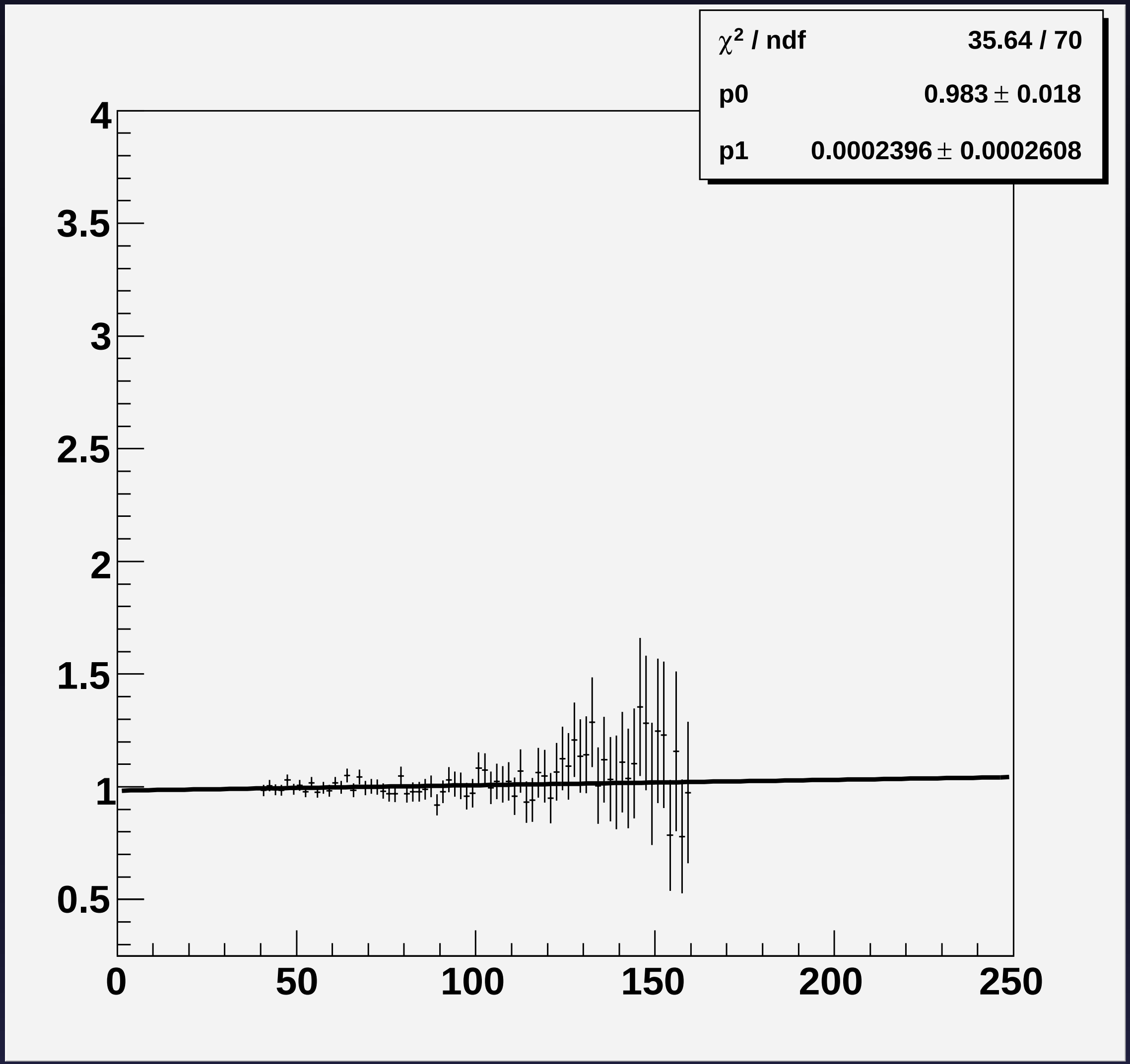
- Status of momentum slope out of fitter
- Next steps

Recap of Data/MC Problem

- Two choices:
  - Data/(Best Fit MC) ratio plots using plots out of KTeVana.
  - Data/(Reweighted Flat MC) ratio plots using plots out of my likelihood fitter.
- The two methods are not consistent
  - They should be
  - Biggest problem: a large data/MC momentum slope out of the fitter which isn't present in the analysis plots......

What should happen

- Ratio of (data)/(Best Fit MC) from KTeVana for the 97 vac momentum plots:
- Not case for fitter

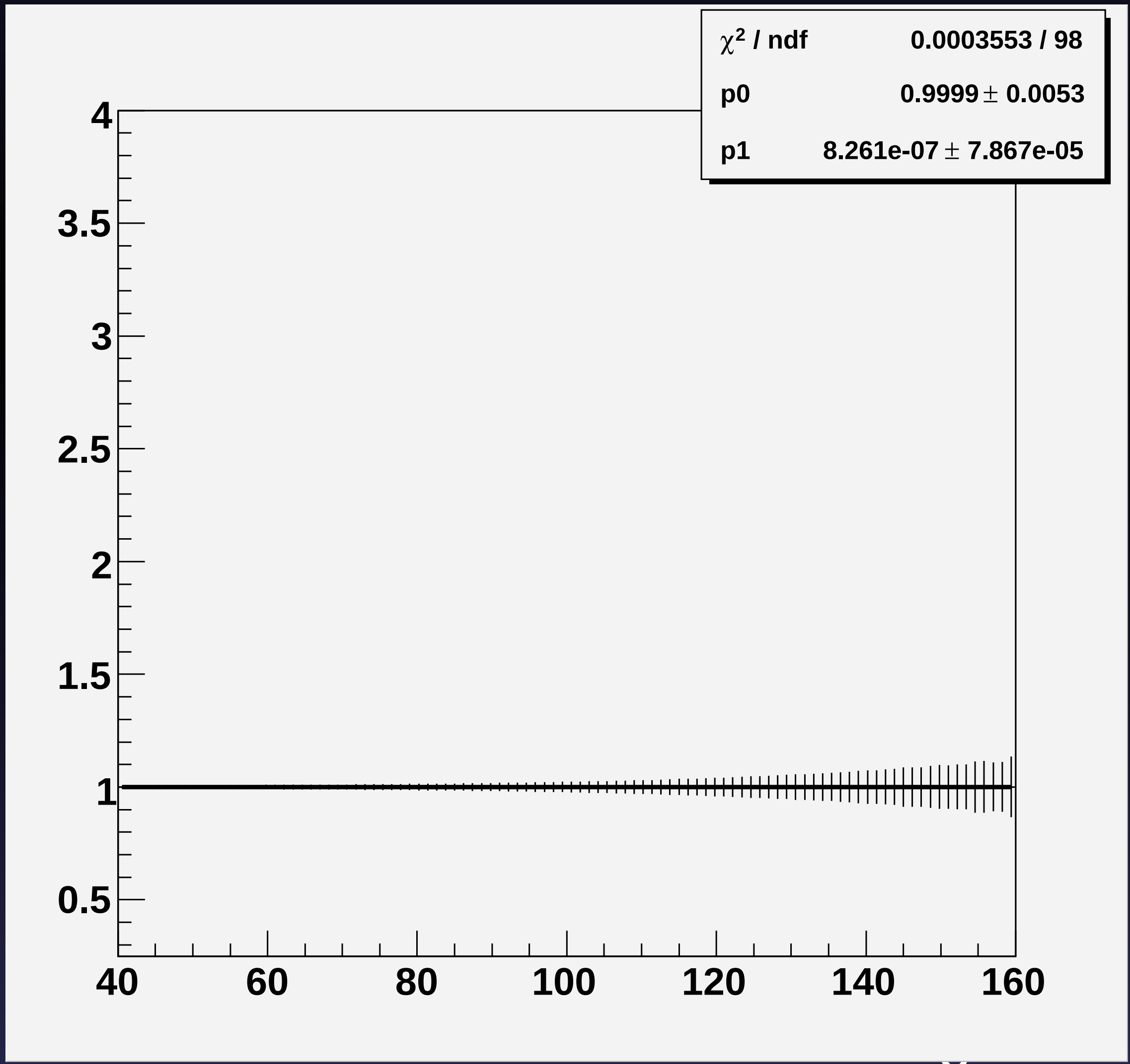


Tests --- Reweighting of Best Fit MC

- Can also feed Best Fit MC into fitter, and reweight with Best Fit parameters
  - Should do nothing
  - Compare plot after reweighting to plot before
  - No slopes introduced into vacuum beam plots
  - Slopes are introduced into reg beam plots
    - But fit uses reg treatment from KFIT, so this isn't a surprise
- Focus on vac beam, since treatment seems to be okay.......
  - <u>Implies problem lies with treatment of flat MC</u>

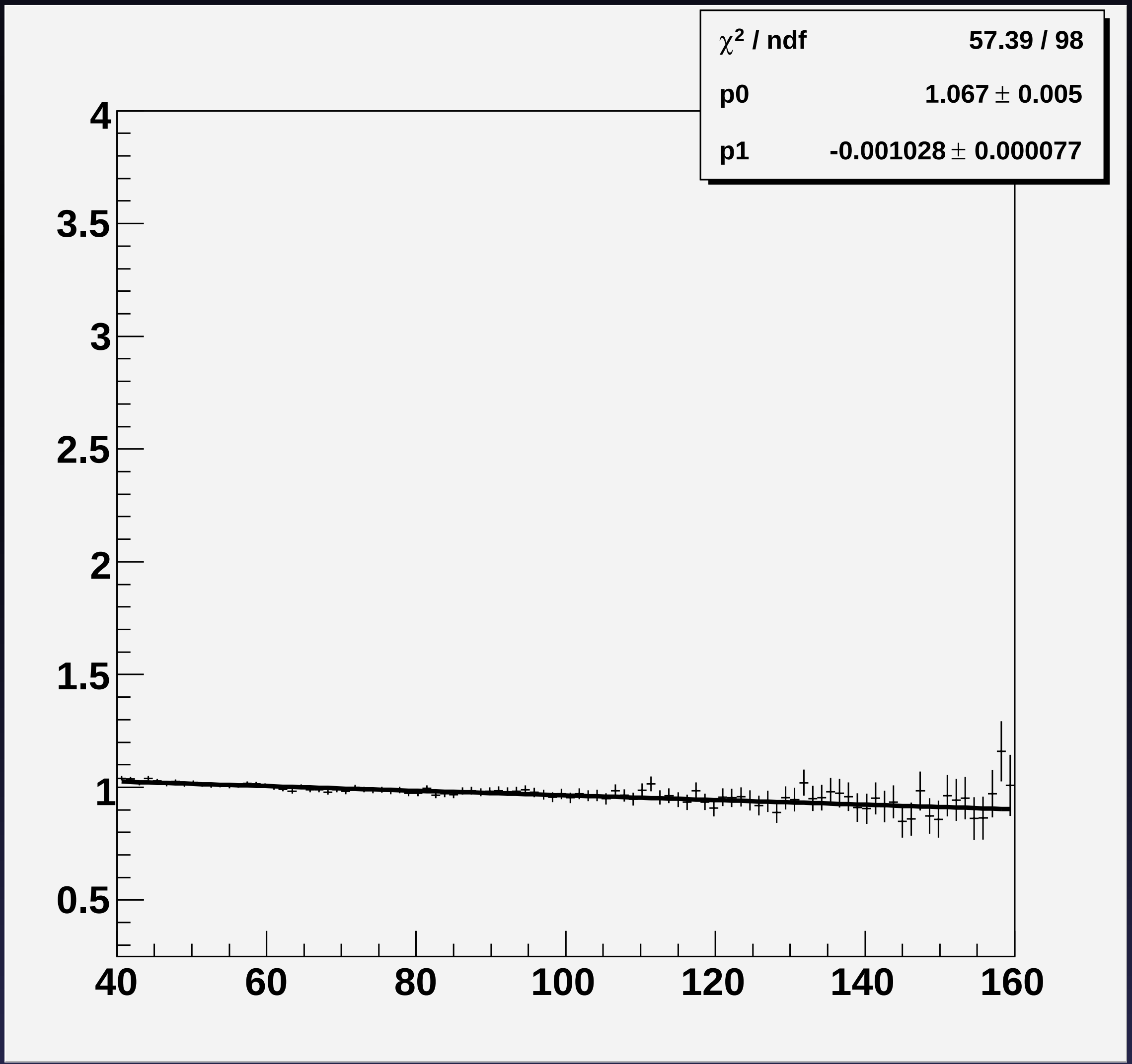
Tests --- Reweighting of Best Fit MC

- Ratio of (Best Fit MC w/o reweighting) / (Reweighted Best Fit MC) for 97 vac momentum
- Or (Before)/(After)



Tests --- Flat MC versus Best Fit MC

- Feed both Flat MC and Best Fit MC into fitter
  - Make separate plots for both samples
  - Ratio of (reweighted Best Fit MC)/(reweighted Flat MC) for 1997 vac beam:
  - Should be flat
  - Isn't



Tests --- Flat MC versus Best Fit MC

- This slope could be due to a underflow issue in the histograms:
  - The histograms are filled with the weight W:
    - W = (new value of decay weight)/(generated value of decay rate)
    - W ~ 1 for best fit MC in most cases
    - $W < 10^{-10}$ for flat MC (generated w =1.0)
  - HBOOK only handles single precision bin contents
  - I've confirmed that the bin contents are NOT being increased for some events in the flat MC sample.
  - I've confirmed that the bin contents ARE being increased for best fit MC.

Tests --- Flat MC versus Best Fit MC

- Fix this by:
  - Rewrite the entire fitter in C++ so I can use ROOT.
    - bad joke, sorry
  - Or, spread flat MC sample over MANY jobs so that histograms do not overflow.
    - Then convert HBOOK files into ROOT files and then add together.
  - Or, output event data, with new weight from fitter, into a text file
    - Read text file using ROOT to make plots
  - Or, output event data, with new weight from fitter, into a double precision CW Ntuple
    - Sasha G told me how to do this during my FIRST WEEK at UVa!

To Do

- Fix issue with flat MC
  - Numerical problem?
    - This is confirmed. Is it enough?
  - Overlooked weight in flat MC?
  - ?????
- Confirm treatment of reg beam is okay

To Do – From Last Meeting......

- Once momentum issue is dealt with, measure momentum and z slopes out of fitter and redo the “flattening” systematics
  - Also attempt to determine correlation between z slope and momentum slope, and properly propagate error
- Produce “smoking gun plots”
  - data/MC ratios for E_γ and τ seem to work
  - So may Brad's subtraction idea

To Do

- Check resolution systematic and ensure that observed shift was not due to statistical fluctuation
- Check for double counting from the p_T^2 cut variation systematic and background systematic .
- Check E_γ (Lab Frame) cut variation – too many events added or removed?
- Recheck other cut variations as well

To Do

- Rethink the correlations between cut variations...
- Draw total error ellipse and extract total correlations between fit parameters ala Appendix D from Epsilon Prime PRD
- Carefully recalculate the systematic error on $\eta_{+-\gamma}$ --> compute each individual shift using shifts in ehat, etc.

Extra Slides

Decay Rate for $K_{L,S} \to \pi^+\pi^-\gamma$

- The decay rate is:

$$\frac{dN}{d\tau\, dE_\gamma\, d\cos(\theta)} = N_K \left[|\rho^2| \left[\frac{d\Gamma_{K_S\to\pi^+\pi^-\gamma}}{dE_\gamma\, d\cos(\theta)} \right] e^{-\frac{\tau}{\tau_s}} + \left[\frac{d\Gamma_{K_L\to\pi^+\pi^-\gamma}}{dE_\gamma\, d\cos\theta} \right] e^{-\frac{\tau}{\tau_L}} + 2\,Re\left[\rho \frac{d\gamma^*_{LS}}{dE_\gamma\, d\cos(\theta)} e^{i\Delta m_K \tau} \right] e^{-\left(\frac{1}{\tau_L}+\frac{1}{\tau_S}\right)\frac{\tau}{2}} \right]$$

where:

$$\frac{d\gamma_{LS}}{dE_\gamma\, d\cos(\theta)} \propto \left[E_{IB}(K_L) + E_{DE}(K_L) \right] * \left[E^*_{IB}(K_S) + E^*_{DE}(K_S) \right] + M(K_L) M^*(K_S)$$

$$\frac{d\Gamma_{K_L\to\pi^+\pi^-\gamma}}{dE_\gamma\, d\cos(\theta)} \propto \left| E_{IB}(K_L) + E_{DE}(K_L) \right|^2 + \left| M(K_L) \right|^2$$

$$\frac{d\Gamma_{K_S\to\pi^+\pi^-\gamma}}{dE_\gamma\, d\cos(\theta)} \propto \left| E_{IB}(K_S) + E_{DE}(K_S) \right|^2$$

Direct Vs Indirect CP Violation in E1

- The E1-DE K_L amplitude is a mixture of direct CP and indirect CP violating terms
- g_{E1} part of amplitude is present in K_L and K_S
- E-hat part is present in K_L only

$$|K_L\rangle \propto |K_2\rangle + \epsilon |K_1\rangle$$

Indirect CP Violation (via mixing)

Direct CP Violation (In Decay)

$\hat{\epsilon}$

g_{E1}

$\pi^+\pi^-\gamma$ via E1

$\pi^+\pi^-\gamma$ via E1

Decay Amplitudes

$$E_{IB}(K_S)=\left(4\frac{M_K{}^2}{E_\gamma^2}\right)\frac{e^{i\delta_0}}{1-\beta^2\cos^2(\theta)}$$

CP conserving

$$E_{IB}(K_L)=\left(4\frac{M_K{}^2}{E_\gamma^2}\right)\frac{\overbrace{\eta_{+\,-}}^{\epsilon+\epsilon'}\;e^{i\delta_0}}{1-\beta^2\cos^2(\theta)}$$

CP violating

$$M(K_S)=i\,\epsilon\,g_{M1}\left(\frac{a_1/a_2}{M_\rho^2-M_K^2+2E_\gamma M_K}+1\right)e^{i\delta_1}$$

CP violating

$$M(K_L)=i\,g_{M1}\left(\frac{a_1/a_2}{M_\rho^2-M_K^2+2E_\gamma M_K}+1\right)e^{i\delta_1}$$

CP conserving

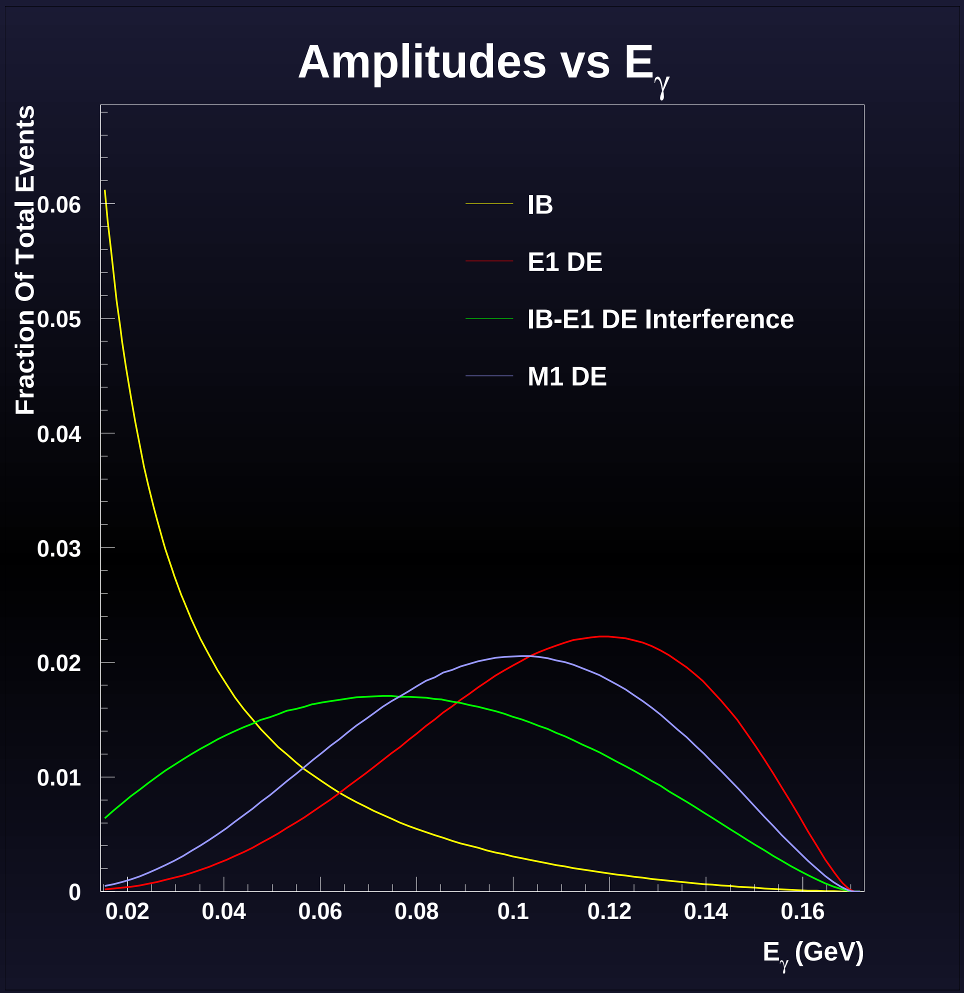
$$E_{DE}(K_S)=\frac{g_{E1}}{\epsilon}e^{i(\delta_1+\phi_\epsilon)}$$

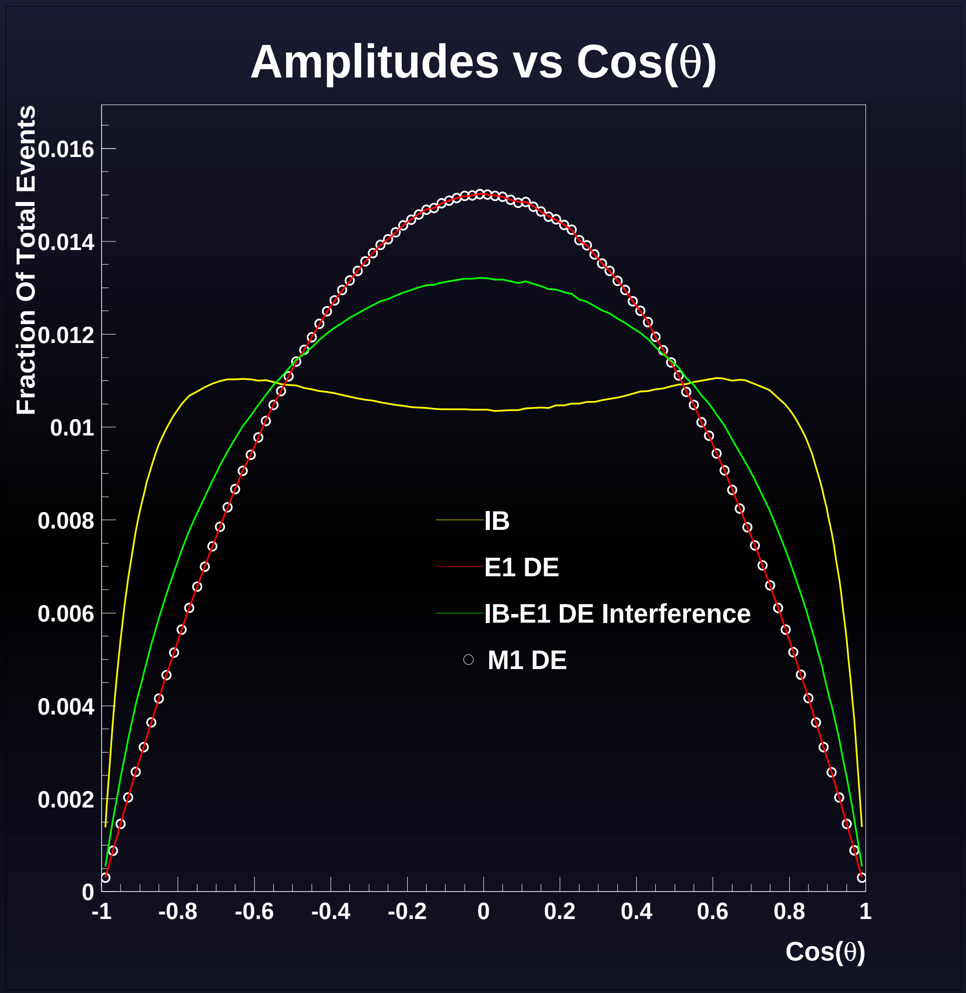
CP conserving

$$E_{DE}(K_L)=\underbrace{g_{E1}e^{i(\delta_1+\phi_\epsilon)}}_{\text{indirect CPV}}+\underbrace{i\,16\,\hat{\epsilon}\,e^{i\delta_1}}_{\text{direct CPV}}$$

CP violating

Amplitudes



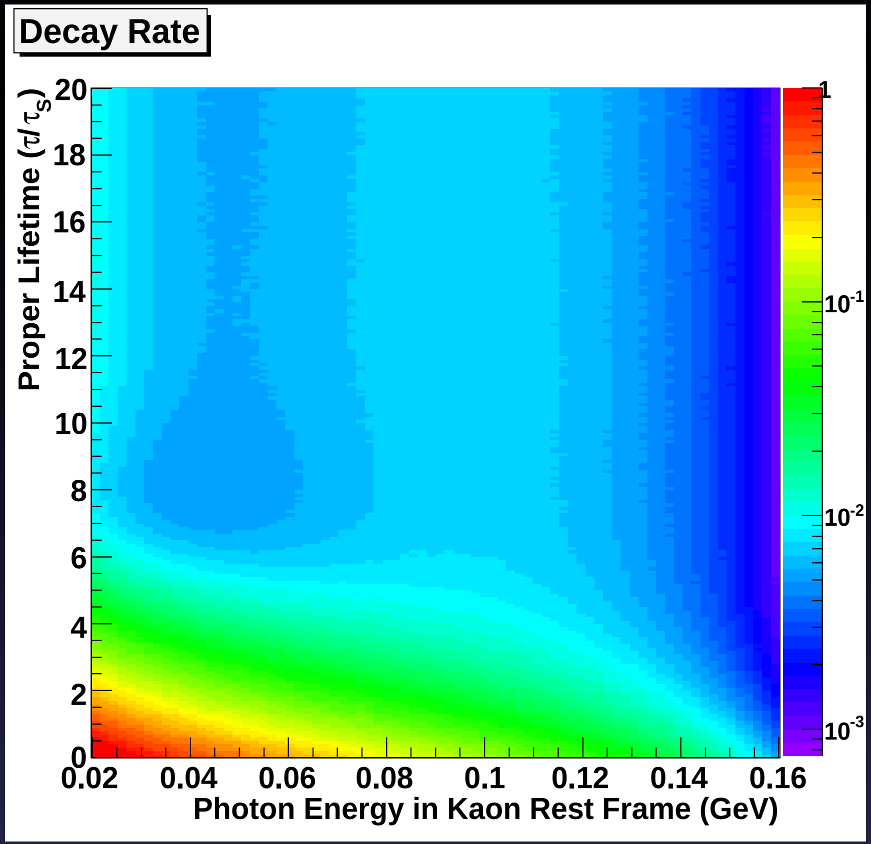


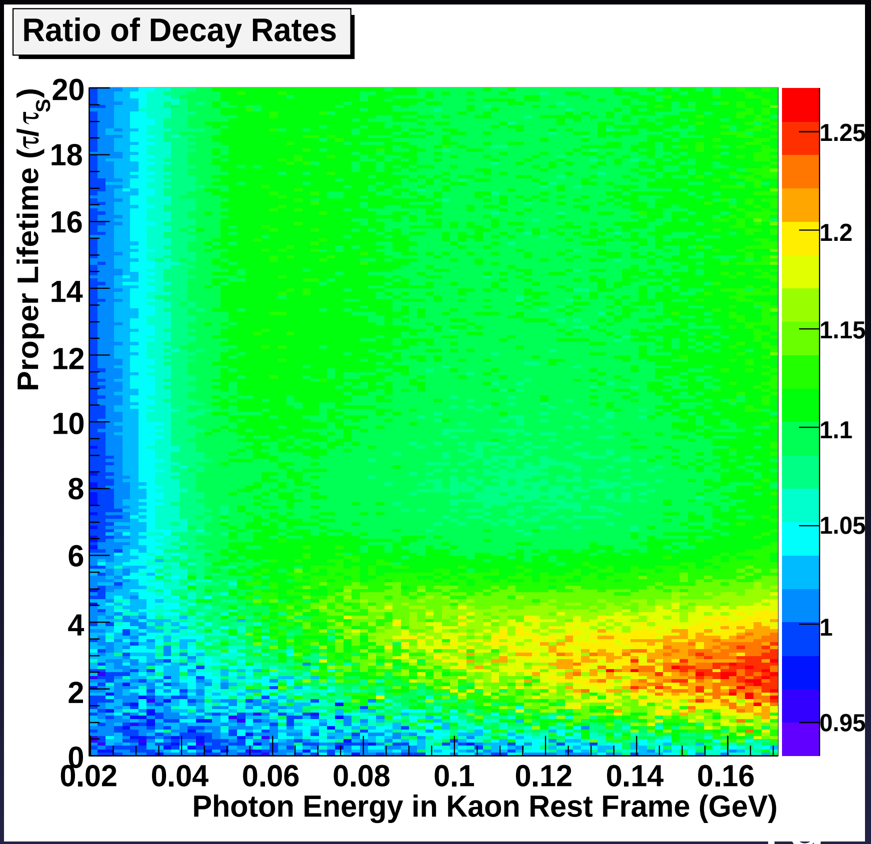
Dependence On E_γ

Dependence On $\cos\theta$

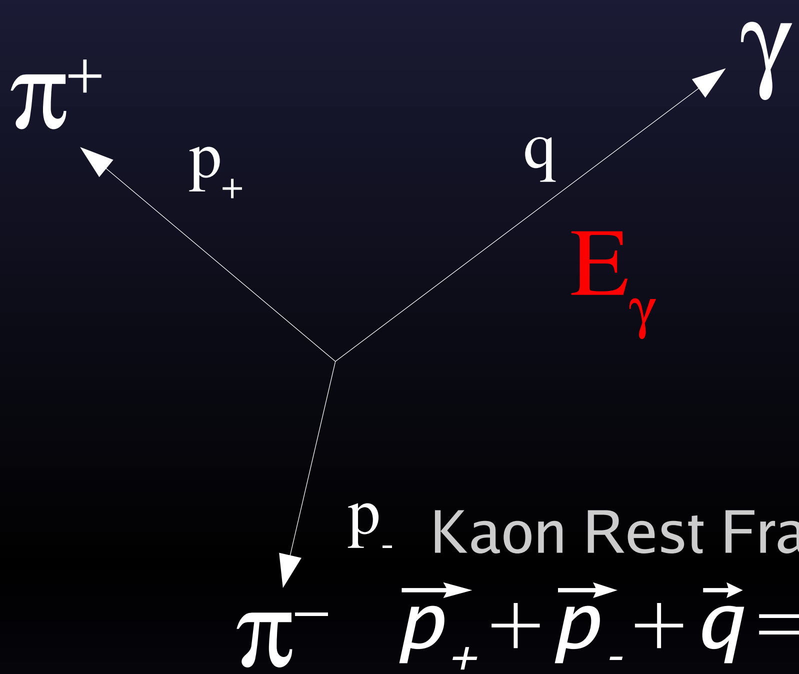
Projections of Decay Rate

- The decay rate will give the density of events in phase space (τ, E_γ, $\cos\theta$)
- Plot of photon energy versus proper lifetime is interesting:



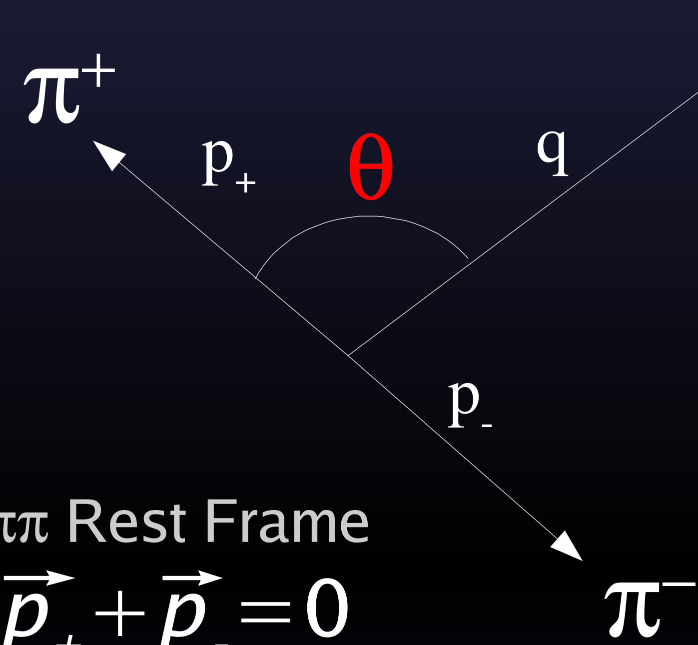


Kinematic Variables for $K\to\pi^+\pi^-\gamma$



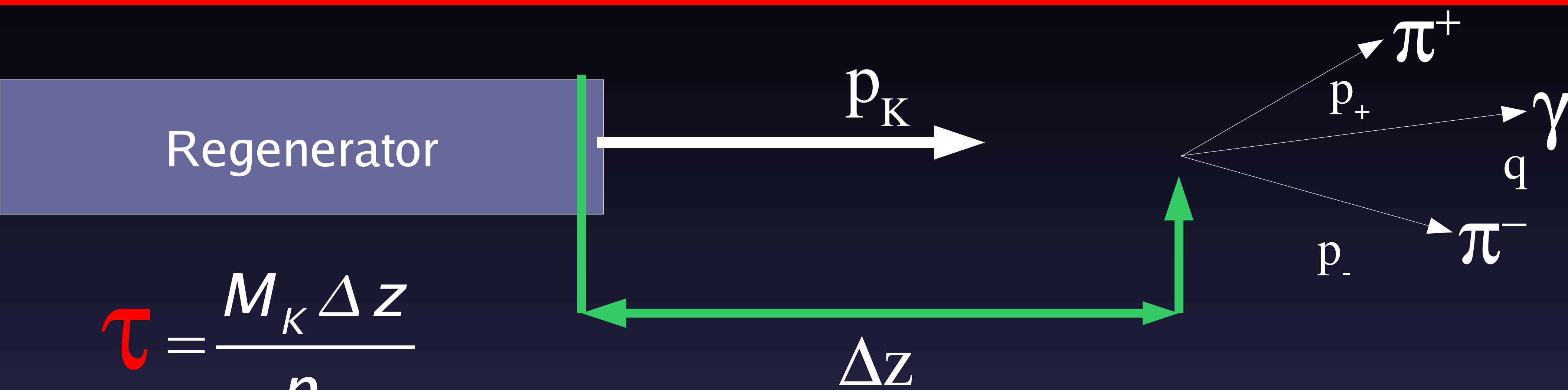
Kaon Rest Frame

$$\vec{p}_+ + \vec{p}_- + \vec{q} = 0$$



ππ Rest Frame

$$\vec{p}_+ + \vec{p}_- = 0$$



Lab Frame

$$\tau = \frac{M_K \Delta z}{p_K}$$

Analysis Cuts

Cut Variable	**Keep Event If...**
Kaon Mass	$0.48967\ GeV/c^2 < M_{\pi^+\pi^-\gamma} < 0.50567\ GeV/c^2$
P_T^2w.r.t Regenerator	$P_T^2 < 2.5 \times 10^{-4}\ GeV^2/c^2$
Kaon Momentum	40.0 GeV/c $< P_{\pi^+\pi^-\gamma} <$ 160.0 GeV/c
Photon Energy in Lab Frame	$E_\gamma^* > 1.5$GeV
Photon Energy in Kaon Rest Frame, From Calorimeter	20.0MeV $< E_\gamma^* <$ 175.0 MeV
Photon Energy in Kaon Rest Frame, From Kinematics	20.0MeV $< E_\gamma^* <$ 175.0 MeV
$\pi\pi$ Invariant Mass, Implied From Above Cut	$0.2711\ GeV/c^2 < M_{\pi\pi} < 0.4772\ GeV/c^2$
Shape χ^2 For Photon Cluster	$\chi^2 < 48$
Outer Fiducial Cut For Photon Cluster	`ISEEDRING` < 18.1 cm
Inner Fiducial Cut For Photon Cluster	`ISMLRING2` > 4.5 cm
Photon/Track Separation at CsI	d > 30 cm
Number of CsI clusters	`NCLUS` ≥ 3
pp0kin w.r.t. Target	-0.10 $GeV^2/c^2 < P^2_{\pi^0} <$ -0.0055 GeV^2/c^2
L3 pp0kin	passes
Z vertex	125.5 m < `VTXZ` < 158.0 m
E/p	E/p < 0.85
Track Momentum	`TRKP` > 8.0 GeV
Vertex χ^2	`VTXCHI` < 50.0
Magnet Offset χ^2	`TRKOCHI` < 50.0
Track x separation at CsI	$\Delta x > 3.0$ cm
Track y separation at CsI	$\Delta y > 3.0$ cm
Total track separation at CsI	$\Delta r > 20.0$ cm
Number of Tracks	`NTRK` = 2
$\Lambda \to p\pi$ invariant mass	$M_{p\pi} < 1.112 GeV/c^2$ or $M_{p\pi} > 1.119 GeV/c^2$
Early energy in photon cluster	`ADCSI_EARLY` < 150 counts
In-time energy in photon cluster	`ADCSI_INTIM` > 115 counts
Photon/Upstream Track Projection at CsI	d > 2.0cm distance
Reconstruction Routines	Return no errors
Veto Cuts	All pass
Level 1 Trigger Verification	Event passes
Fiducial Cuts	All pass
Number of Photon Candidates That Pass ALL Cuts	$N_{COMBINATIONS} = 1$ ONLY